Searches for BSM physics at LHC with ATLAS

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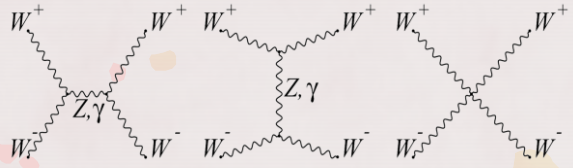
Why BSM? 1

- If SM Higgs exists
  - To solve the hierarchy and naturalness problems
    - Quadratic divergence of Higgs mass
  - O(1 TeV)

$$\delta m_H^2 = \quad = \frac{y_f^2 v^2}{16\pi^2}\Lambda^2$$

- If SM Higgs does not exist
  - New mechanism for EWSB
  - O(1 TeV)



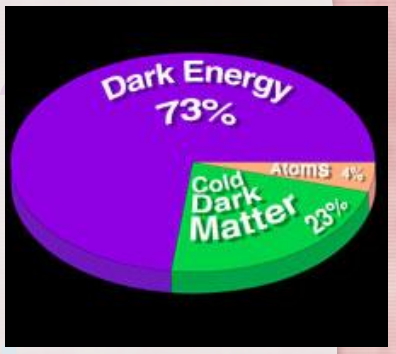
Unitarity Violation in W^+W^- scattering

$$\sigma_{W^+W^-\to W^+W^-} \propto \frac{1}{v^2}(s+t)$$

- O(1 TeV) is the scale of BSM physics related to EWSB

Why BSM? 2

- SM cannot give the answers to the problems
  - Dark Energy (73%), Dark Matter (23%)
  - Baryogenesis / Leptogenesis (4%)
  - Charge quantization
  - Fermion mass/mixing
  - Unification of EW and strong/gravity interactions.
  - …
- Need BSM physics to solve the problems
- BSM scale depends on model
  - $O(10^3\ \text{GeV}) \sim O(10^{19}\ \text{GeV})$
- should search at Energy Frontier



BSM Scenarios

- SUSY (not covered in this talk)
- Extra Dimension
  - G, KK particles, Radion, Black Hole, String Ball
- GUT
  - W', Z', H^{++}, ν_R, LQ, heavier quarks/leptons, diquarks
- Little Higgs
  - A_H, Z_H, W_H, T, H^{++}
- Hidden Valley
  - π_ν, η'_ν, σ_ν, σ'_ν, ω_ν
- Technicolor
  - ρ_T, ω_T, π_T
- Many others…
- Models not yet thought/built

- ATLAS searches BSM by signature based analyses

Signatures

- Lepton/photon + X
  - W', Z', G, KK particles, ν_R , heavier quarks/leptons
  - LQ, Technimesons, H^{++}, Radion
- Jet + X
  - KK particles, G, heavier quarks
- Long lived
  - π_v, H^{++}, Magnetic Monopoles
- Diboson
  - Technimesons, H^{++}, Radion
- Busy events or multi high p_T object
  - Black Holes, String Balls

Randall-Sundrum ED

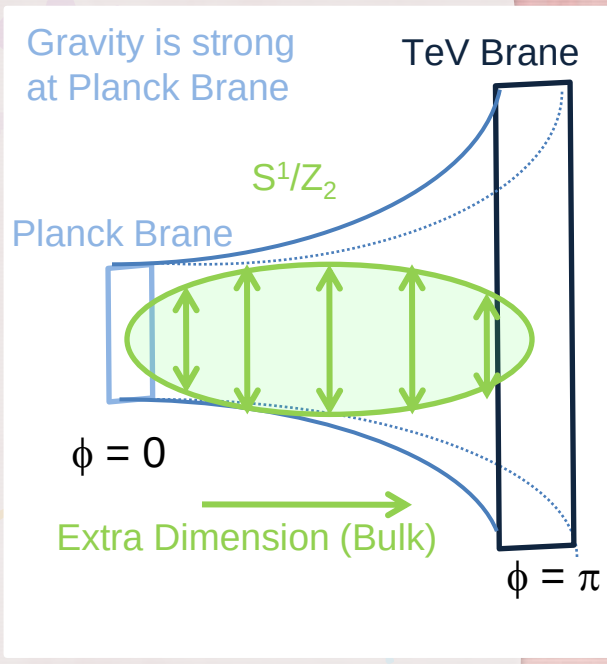
- 4 + 1 dimensions
  - ED compactified on S^1/Z_2 orbifold.
  - Two 3D branes are displaced in ED direction
    - SM particles localized in TeV Brane
    - Only graviton can propagate to bulk → massive KK Gravitons : G_{KK}
  - The metric of the model is

$$ds^2 = e^{-2kr_c\phi}\eta_{\mu\nu}dx^\mu dx^\nu + r_c^2 d\phi^2$$

Warped Factor

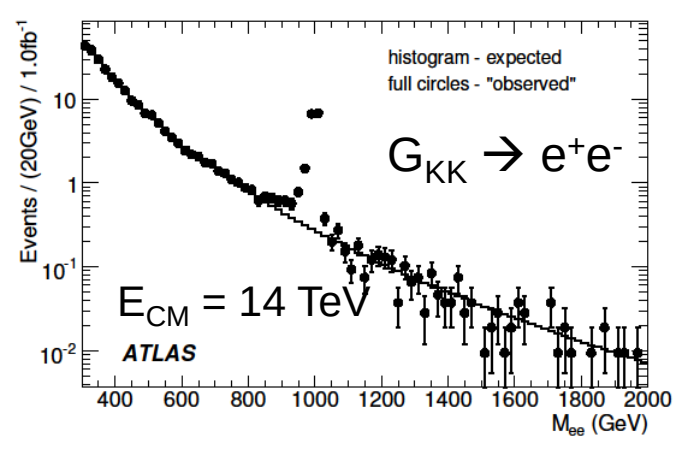
$0 \le \phi \le \pi$

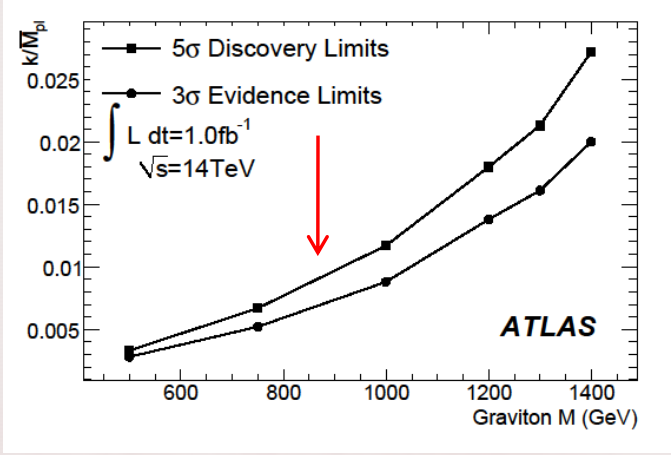
    - k : curvature of ED
    - r_c : radius of orbifold
  - Real Planck scale Λ
    - $\Lambda = M_{pl} * \exp(-kr_c\pi)$, if $kr_c \sim 12$ → $\Lambda \sim O(1\text{TeV})$
    - Solve the hierarchy problem !



Dilepton Resonance : $G_{KK} \rightarrow e^+e^-$

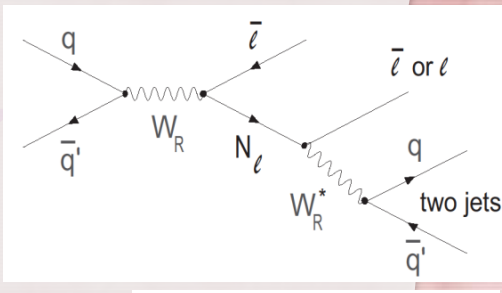
- Two Model Parameters
  - Coupling : $k/M_{pl} = 0.01 \sim 0.1$ ($M_{pl} = \Lambda * \exp(kr_c\pi)$)
  - Mass of 1st KK state : M_G
- KK Graviton
  - Mass : $M_n = x_n * k/M_{pl} * \Lambda$ with Bessel function $J_1(x_n) = 0$
  - Narrow resonance with leptonic branching fraction of 2%
  - Tevatron Limit $M_G > 300$GeV for coupling = 0.01
  - mass up to 900GeV with coupling of 0.01 can be observed with $1fb^{-1}$

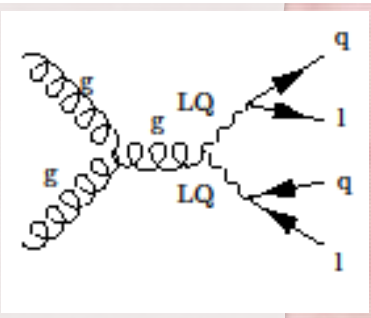




Extended Gauge Sector

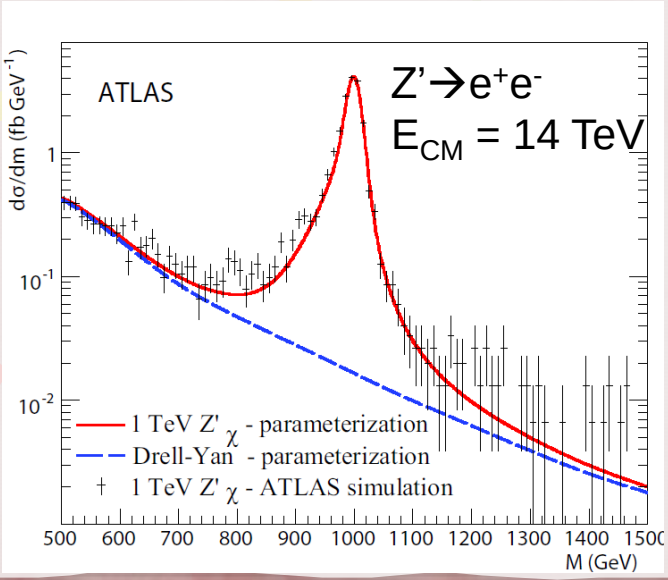
- Left Right Symmetric Models (LRSM)
  - $SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$
  - New particles : Z', W'_R, ν_R, $H^{++}{}_R$, $H^{++}{}_L$
- Pati-Salam model
  - Color SU(4) : lepton number is 4th color, RGBL
  - New particles : leptoquarks
- Additional U(1) models
  - New particles : Z'
  - Coupling of Z' to SM particles could be different from Z
- GUT
  - Unification of EW and strong interaction
  - Solve Baryogenesis, Charge quantization
  - SO(10), E_6, ~~SU(5)~~ ....
    - Above three models can be subgroups.
- New bosons, matter particles appear !



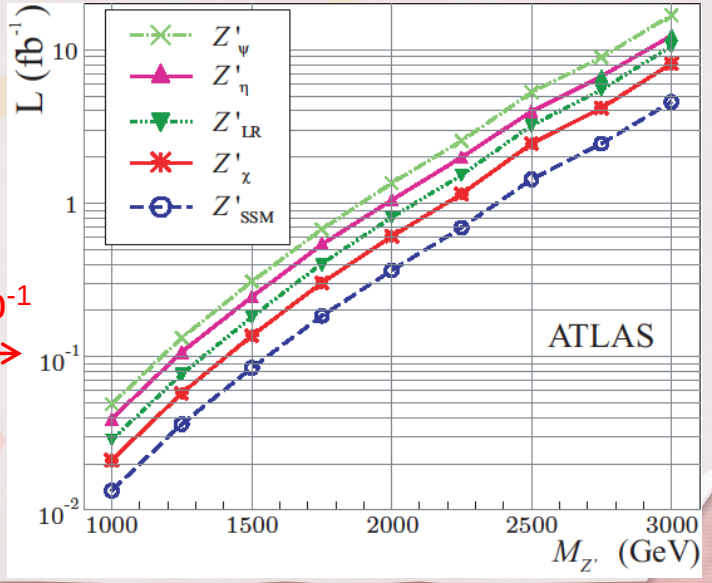


Dilepton Resonance : Z' → l^+l^-

- Z'
  - Leptonic decays are very clean.
  - Tevatron 95 % CL limit : M ~ 1TeV
  - 1 TeV Z' can be observed with < 100pb^{-1} at E_{CM} = 14 TeV
    - Studies at E_{CM} = 7 ~ 10 TeV are ongoing.



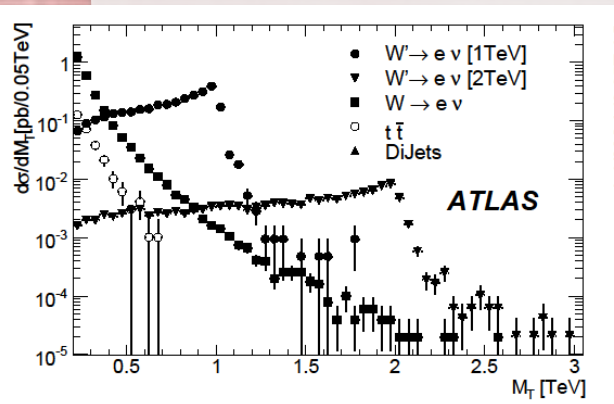
100 pb^{-1} →



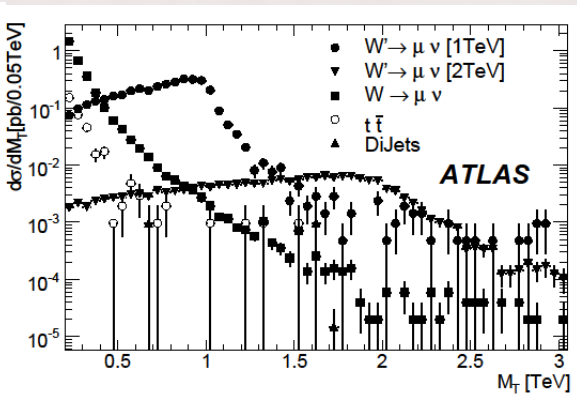
Lepton + Missing E_T : W'→ l ν

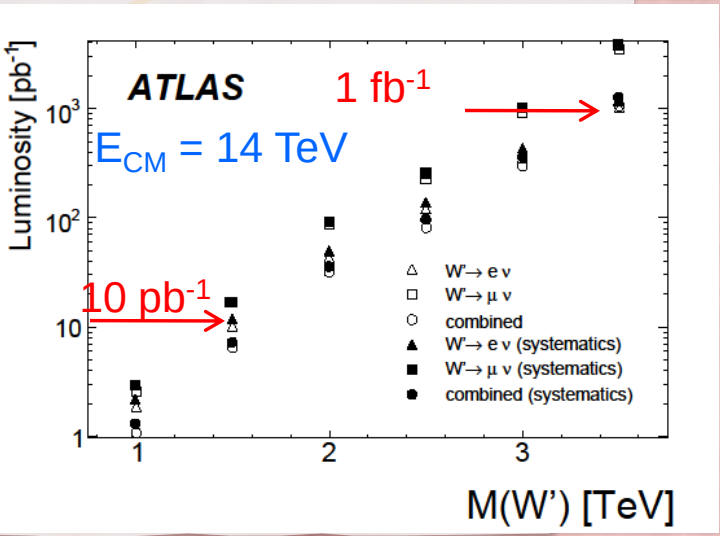
- W'
  - Tevatron Limit ~1 TeV
  - Transverse mass is calculated from lepton p_T and missing E_T
  - 1 TeV W' can be observed with < $10pb^{-1}$ at E_{CM} = 14 TeV
  - ~3.5 TeV W' with $1fb^{-1}$

W'→e ν



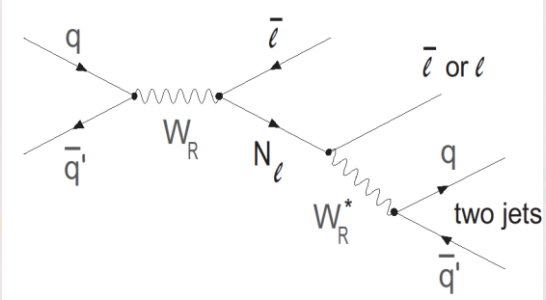
W'→μ ν



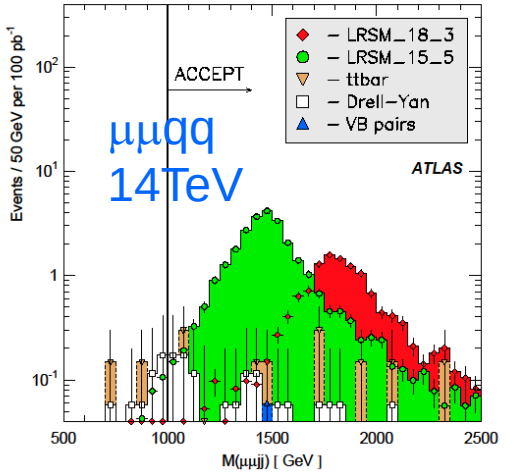


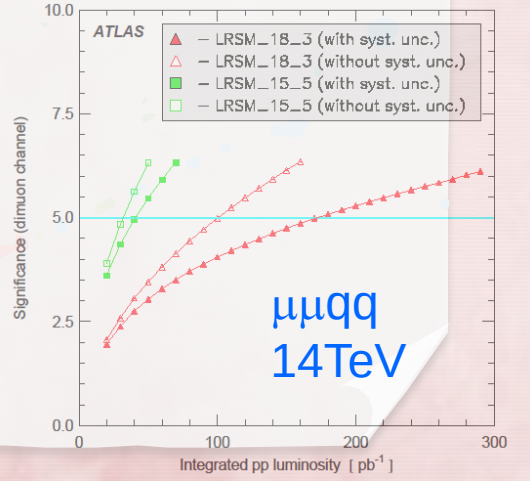
Lepton + Jet : $W_R \rightarrow l^+l^-qq, l^{\pm}l^{\pm}qq$

- LRSM W_R
  - Both same and opposite sign dilepton final states are possible due to majorana ν_R



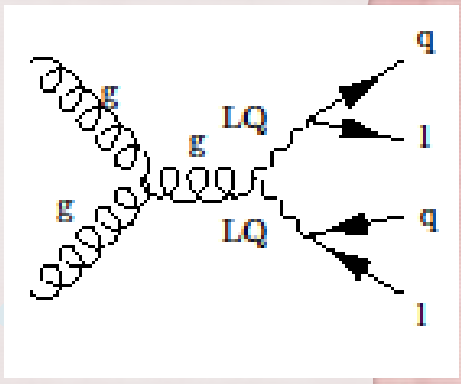
  - Tevatron limit $m_{WR} \sim 800GeV$
  - Two mass points
    - P1 : m_{WR}=1.5 TeV, $m_{\nu R}$=500GeV
    - P2 : m_{WR}=1.8 TeV, $m_{\nu R}$=300GeV
  - P1 can be observed with $50pb^{-1}$
  - P2 can be observed with $200pb^{-1}$



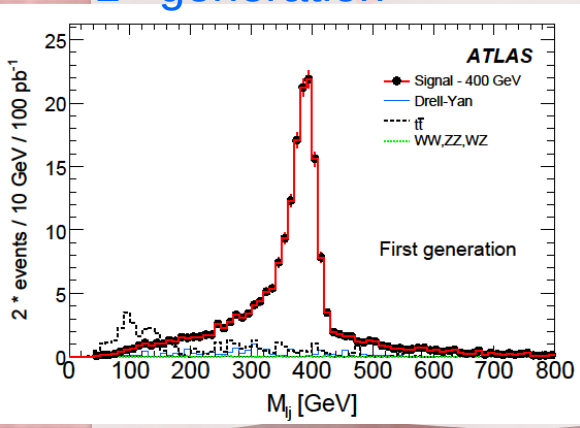


Lepton + Jet : Leptoquark

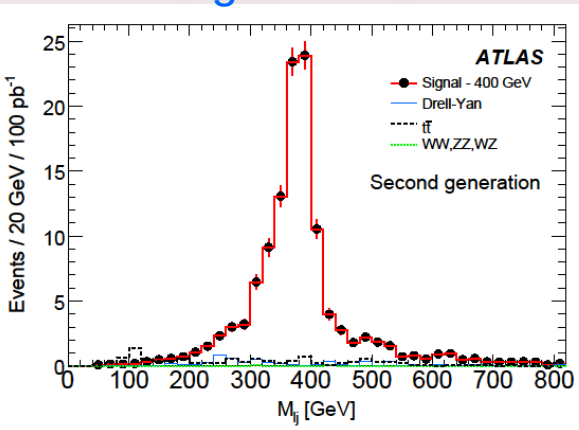
- Scalar Leptoquarks
  - Pair production of LQ
  - Final state : l^+ql^-q
  - Generation conserving
  - Sensitivity : ~470 GeV for $\beta^2 = 1 - M_{LQ}^2/\hat{s} = 0.5$

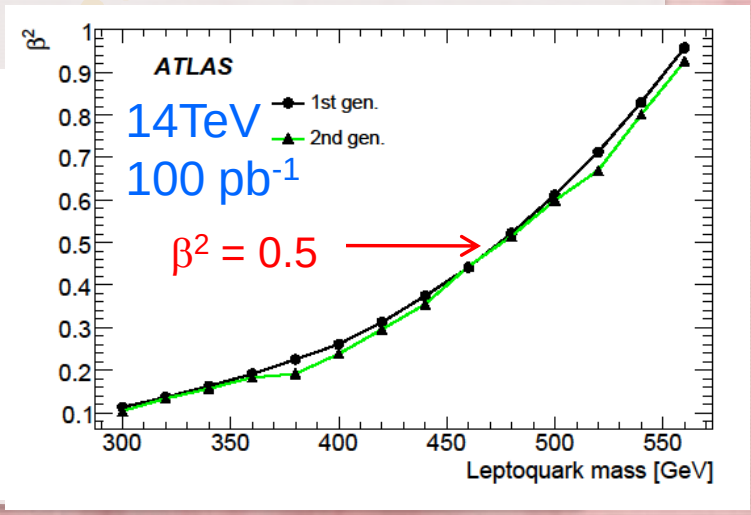


1st generation



2nd generation





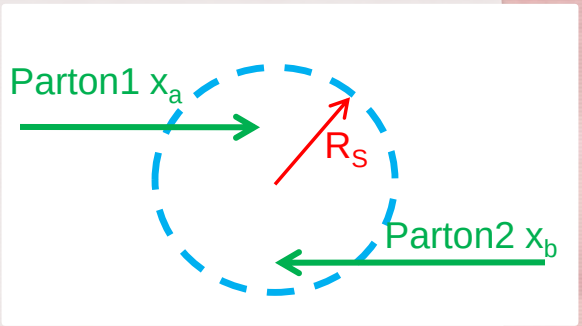
TeV Scale Gravity

- Extra Dimension → Strong Gravity at TeV scale
  - Black Hole production in semi-classical general relativity
    - If $\sqrt{\hat{s}} > 5M_D$
    - M_D : Planck scale in D dimension
  - String Ball production in quantum gravity
    - Highly excited string state
    - Energy scale less than black hole production
    - Black holes may evolve down to string balls

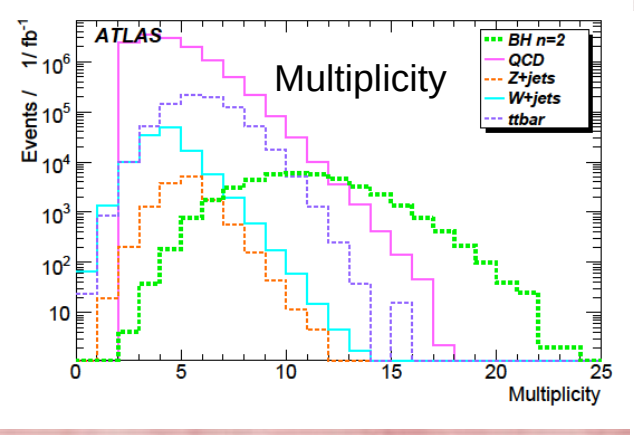
M_S : String scale < M_D
g_s : String coupling < 1.0

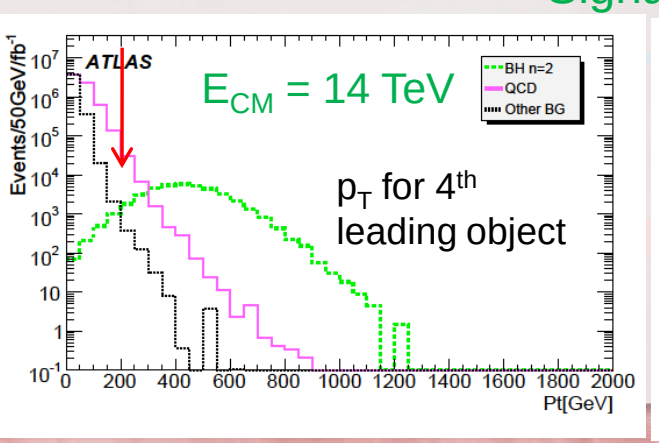
Busy Events : Micro Black Holes

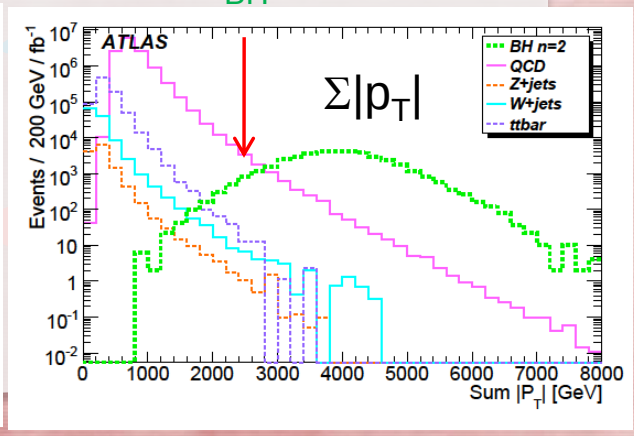
- BH production in D (=4+n) Dimensions
  - Impact parameter for two partons less than twice of Schwarzschild radius R_S
    - $M_{BH} = (s\, x_a\, x_b)^{1/2} > 5M_D$, $M_D \sim O(1TeV)$
    - $R_S \sim 1/M_D * (M_{BH}/M_D)^{1/(n+1)}$
  - Cross section
    - $\sigma_{BH} \sim \pi R_S^2 \sim O(10pb)$ if $M_{BH} \sim 5TeV$
- BH decays via Hawking radiation in $\sim 10^{-27}$ sec
  - High multiplicity (Jet/lepton/photon) : 4 objects with $p_T > 200GeV$
  - High $\Sigma|p_T| > 2.5$ TeV

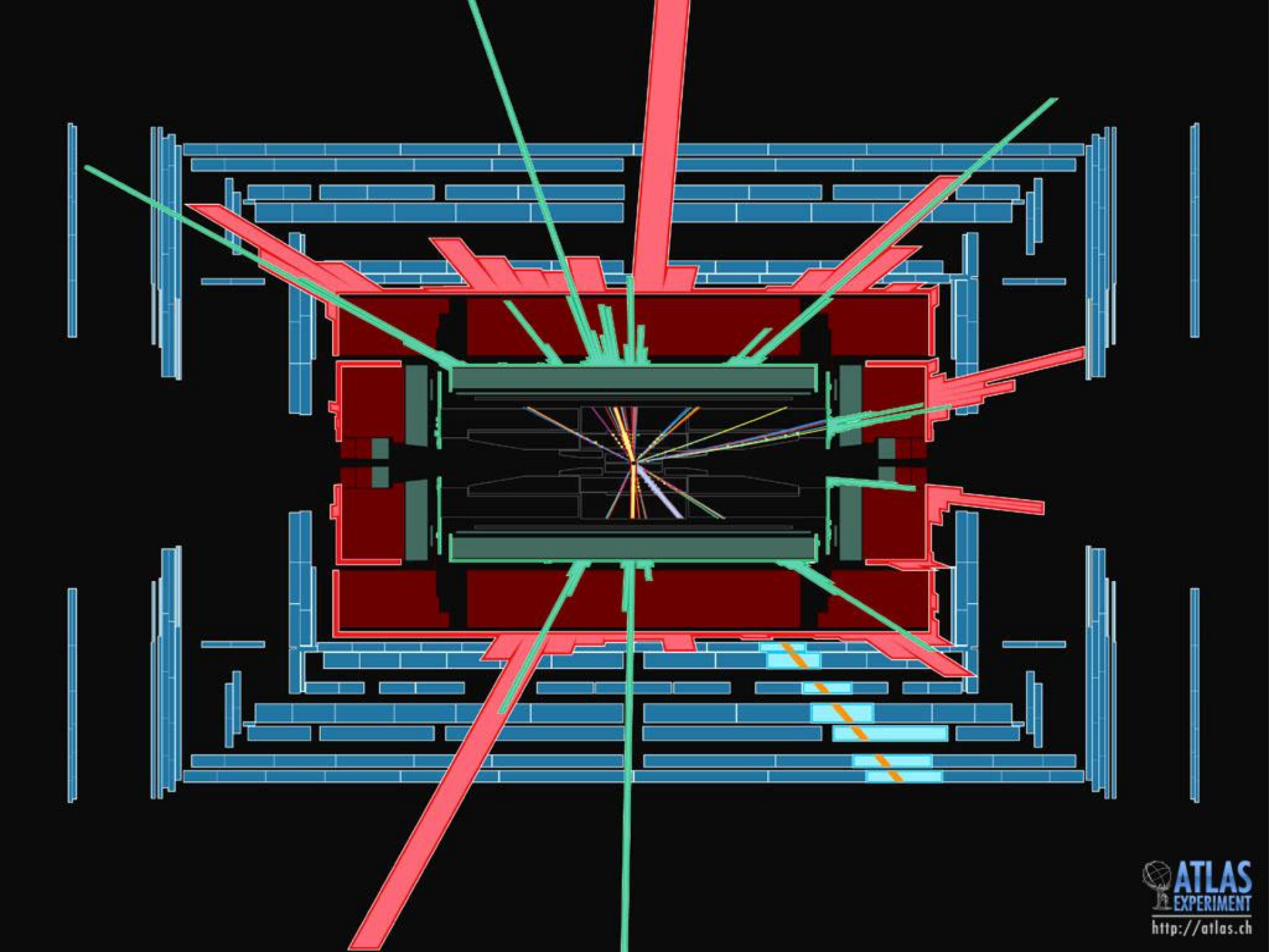


Signal : n=2, $M_{BH} > 5TeV$





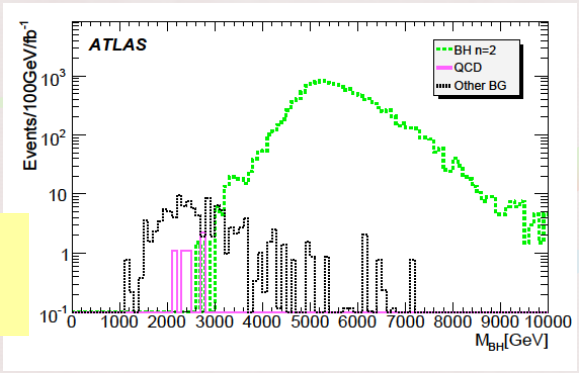


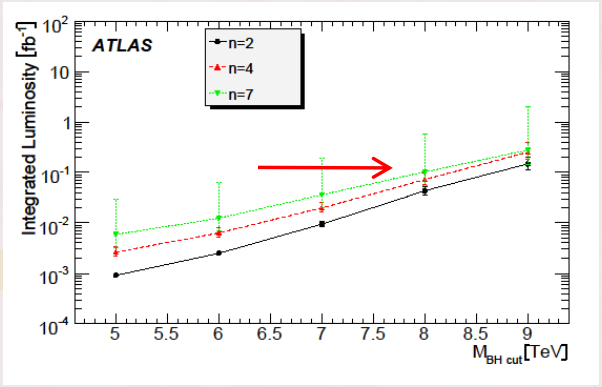

ATLAS
EXPERIMENT
http://atlas.ch

Micro Black Holes

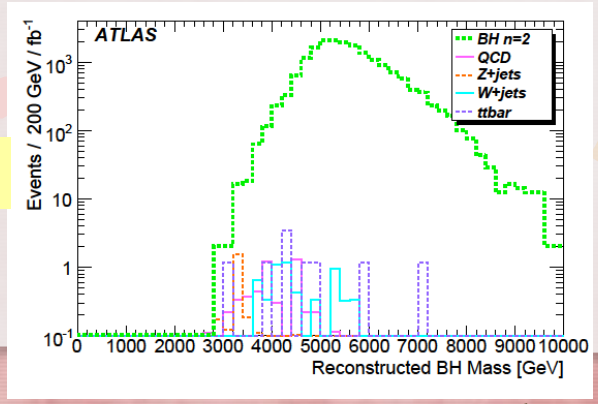
- Decay to all SM particles
  - Requirement of lepton p_T >50GeV eliminates dominant QCD backgrounds
  - With 100pb^{-1}, M_{BH} ~ 8TeV can be observed for both analyses

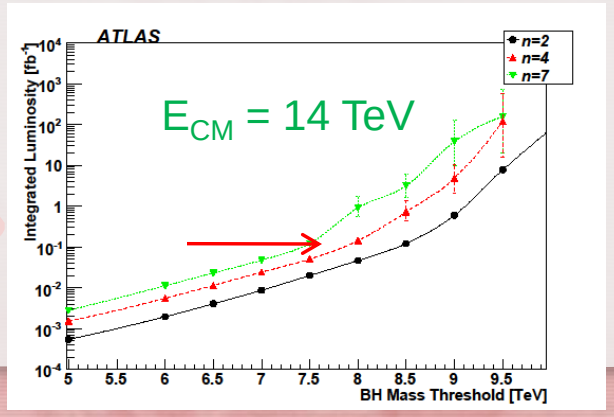
4 high p_T objects + lepton





$\Sigma|p_T|$ + lepton





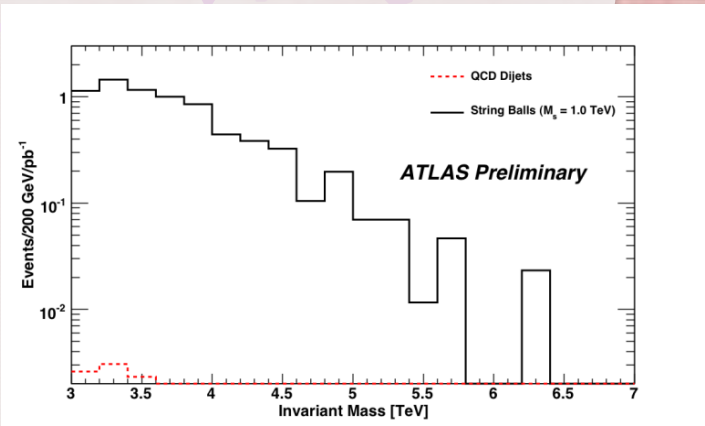
String Ball

- Cross section

$$\hat{\sigma} = \begin{cases} \frac{g_s^2 M^2}{M_s^4} & M_s \ll M \leq \frac{M_s}{g_s}, \\ \frac{1}{M_s^2} & \frac{M_s}{g_s} \leq M \leq \frac{M_s}{g_s^2}, \\ \pi \frac{f^2(n)}{M_D^2} \left(\frac{M}{M_D}\right)^{\frac{2}{n+1}} & \frac{M_s}{g_s^2} < M. \end{cases}$$

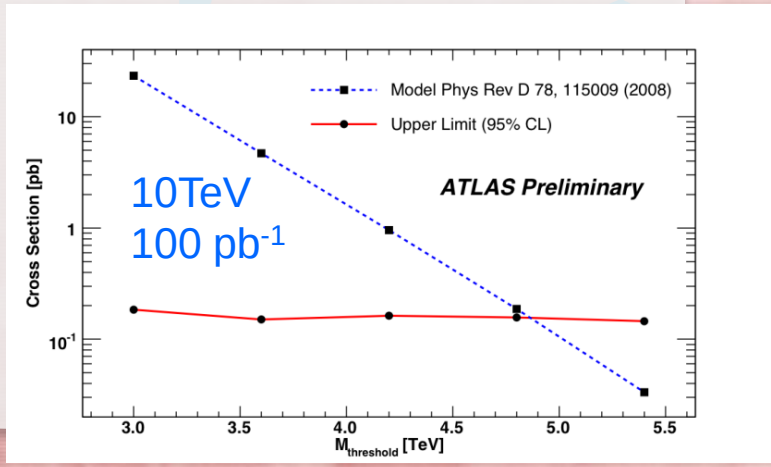
String Ball

Black Hole



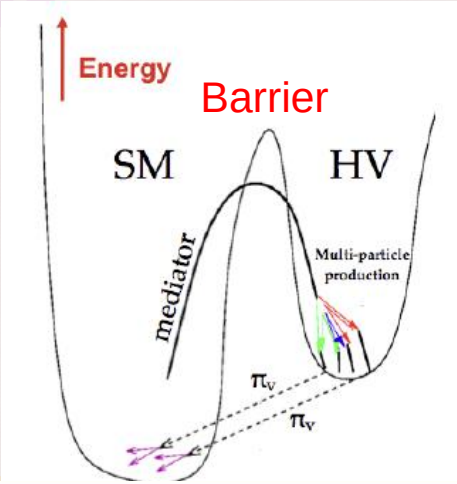
Invariant mass

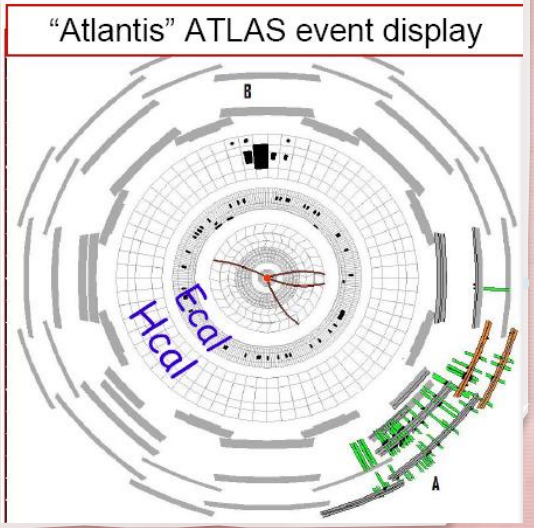
  - σ = 23 pb, if M_S = 1.0TeV, M_D = 1.5TeV, M_{SB}>3.0TeV
- Analysis is the almost same as BH
  - High $\Sigma|p_T| + E_T$ >2.5 TeV
  - High p_T Lepton > 100GeV
- Upper limit on M_{SB} > 4.8 TeV
  - At E_{CM} = 10 TeV with 100 pb^{-1}

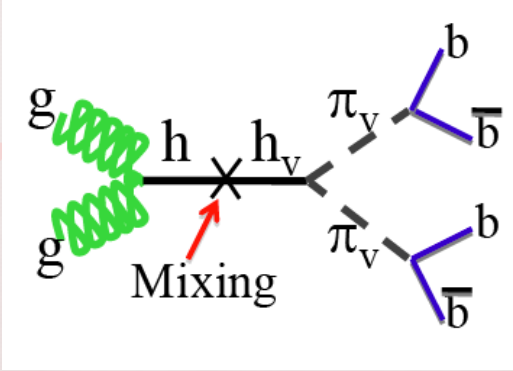


Long Lived Neutral Particles : π^0_ν

- Hidden Valley model
  - Hidden sector + mediator
    - Non-Abelian gauge group, ex. $SU(n_\nu) \otimes U(1)_\chi$
  - Need high energy to produce hidden sector particles
  - Predict long lived pseudo-scalar π_ν^0
    - Lightest hidden particle
    - Dominantly decays to bottom quark pair
      - Due to helicity suprression



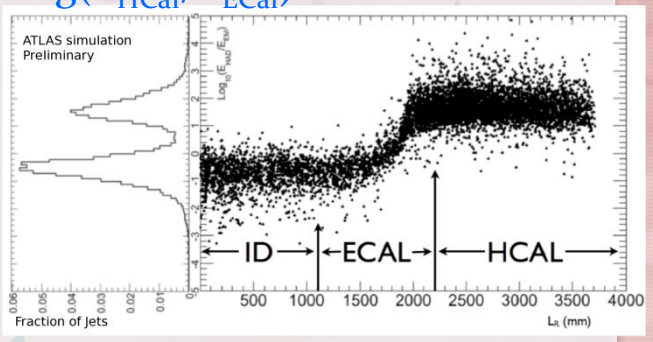


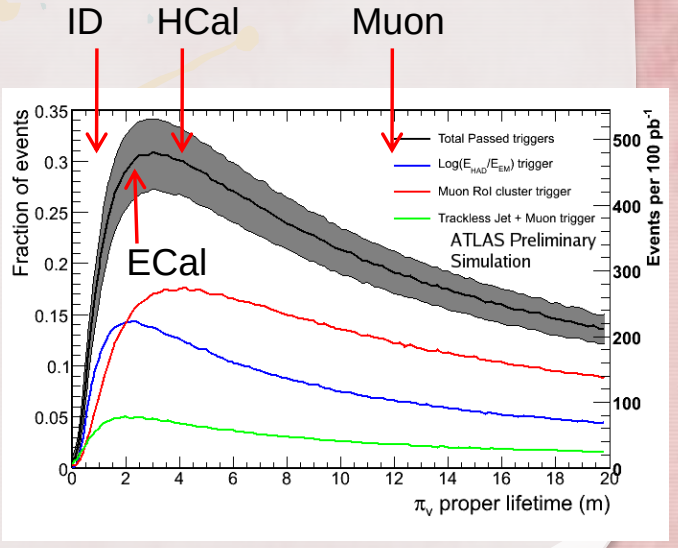


Triggering on π^0_ν

- Lifetime is parameter dependent
  - π^0_ν decays in
    - Outer tracker ~ ECal → trackless Jet
      - L1 muon trigger in addition
    - ECal ~ HCal → large E_{HCal}/E_{ECal}
      - $E_T > 35$ GeV
      - $\mathrm{Log}(E_{HCal}/E_{ECal}) > 1$
      - No Level2 tracks
    - Muon system → clustered L1 muon trigger
      - At least 3 muon L1 Trigger in $\Delta R<0.4$
      - No Level2 jet trigger or tracks
  - Efficiency is high as >10% for proper lifetime longer than 50cm
- Analysis is ongoing

$\log(E_{HCal}/E_{ECal})$





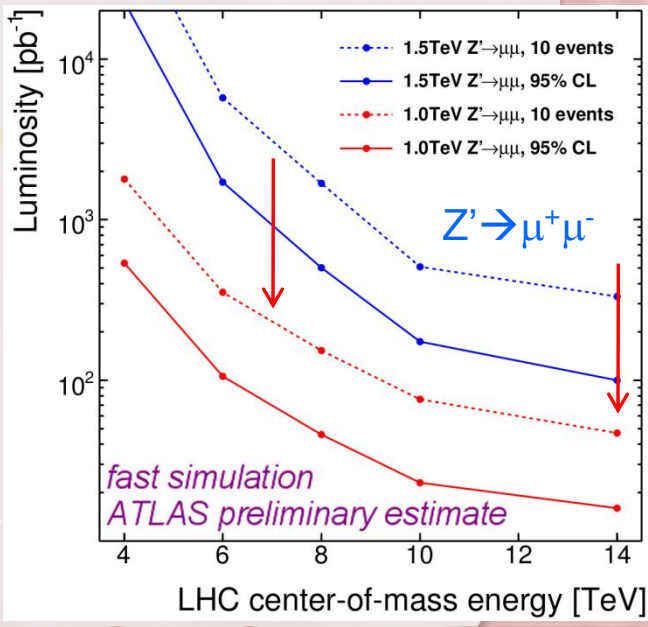
Trigger for long lived charged particles is also in progress but not public

Center of Mass Energy and Its Implications

- "We've selected 3.5 TeV (per beam) to start because it allows the LHC operators to gain experience of running the machine safely while opening up a new discovery region for the experiments." by CERN's Director General, Rolf Heuer.
  - 7 TeV from 2009, until a significant data sample has been collected
  - 10 TeV in 2010, after operations team has gained experience
  - Lead ions collision in the end of 2010
  - After that shut down for 14 TeV

http://press.web.cern.ch/press/PressReleases/Releases2009/PR13.09E.html

- At 7 TeV, about factor 4 larger luminosity is needed to obtain the same physics output for ~1 TeV physics at 14 TeV
  - 1 TeV Z' can be observed with ~100/pb by combining electron and muon modes
  - Of course, sensitivity depends on model.



Conclusion

- ATLAS is ready to search for BSM physics with signature based analyses
- Early observations are possible with ~100 pb^{-1}
  - W', Z', Black Holes, String Balls…
- We are entering new era for high energy physics in the years 2009/2010.

Backup